Movement Quality Visualization for Wheelchair Dance

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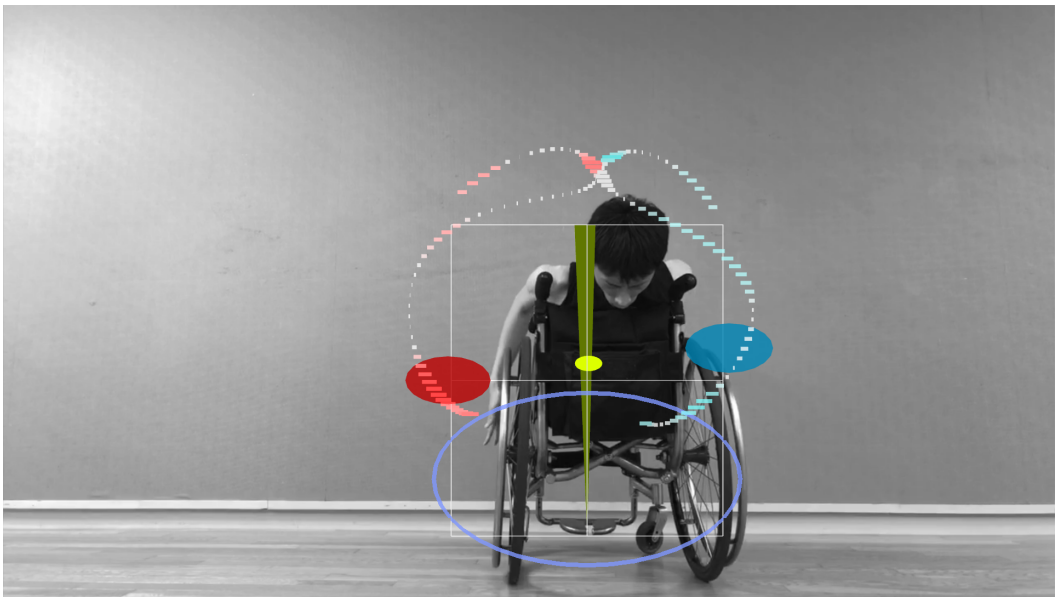

Fig. 1. Visualization Overlapped with Original Choreography. Sun Dance Choreography © Kenta Kambara

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Wheelchair dance is an important form of disability art that is still subject to significant levels of ableism and art exclusion. Wheelchair dancers face challenges finding teachers and choreographers who can accommodate their needs, documenting and sharing choreographies that suit their body shapes and their assistive technologies. In turn, this hinders their ability to share creative expressions. Accessible resources and communication tools could help address these challenges. The goal of this research is the development of a visualization system grounded on Laban Movement Analysis (LMA) that notates movement quality while opening new horizons on perceptions of disabled bodies and the artistic legitimacy of wheelchair dance. The system uses video to identify the body landmarks of the dancer and wheelchair and extracts key features to create visualizations of expressive qualities from LMA basic effort. The current evaluation includes a pilot study with the general public and an online questionnaire targeting professionals to gain feedback supporting practical implementation and real-world deployment. Results from the general public evaluation showed that the visualization was effective in conveying basic effort movement qualities even to a novice audience. Expert consulted via questionnaire stated that the tool could be employed for reflective evaluation, as well as performance augmentation. The LMA visualization tool can support the artistic legitimization of wheelchair dancing through education, communication, performance, and documentation.

CCS Concepts: • **Human-centered computing → Visualization toolkits**; *Accessibility systems and tools*; • **Applied computing → Performing arts**.

Additional Key Words and Phrases: Disability Art, Wheelchair Dance, Movement Qualities, Visualization, Accessibility, Movement Recognition, Laban Movement Analysis

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1 INTRODUCTION

Dance reflects both kinesthetic sense and emotional expression through movement quality [Sutil 2012]. The expressive aspect of the movement conveys the emotion and intention of the dancers. Movement analysis allows movement to be classified as non-ephemeral. The dance field has been incorporating movement analysis to capture and interpret movement quality for performance, style preservation, and educational purposes [Alaoui et al. 2017]. One of the most popular frameworks for movement analysis in dance is the Laban Movement Analysis (LMA) system, which has been widely adopted from the dance industry to human-computer interaction (HCI) [Alaoui et al. 2017].

Limited access to resources hinders the incorporation of established movement analysis and the promotion of artistic value in wheelchair dance. Previous research shows how implementing LMA in folk dances can benefit minority dance forms by preserving artistic quality through evaluation and education [Aristidou et al. 2015].

HCI, new media art, and contemporary dance use a combination of LMA and emerging technologies to analyze movement quality. Wearable motion capture device [Subyen et al. 2011], or depth camera [Anjos et al. 2018], have been leveraged to simplify movement feature extraction for further investigation. Machine learning tools have also been used for movement quality recognition to enrich contemporary dance artistic capacity [Subyen et al. 2011]. However, previous studies only focused on able-bodied dancers. Most research on wheelchair dance focuses on rehabilitation, education [Luna et al. 2022], and entertainment aspects [Takeda et al. 2017]. To our knowledge, visualization of movement quality in wheelchair dance has not yet been explored.

This paper presents a visualization solution specific to wheelchair dance that provides an artistic translation of movement quality based on the LMA's Basic Effort (Figure 1). The design is structured around modules on data capture, feature extraction, and visualization. The visualization system's

design can be adapted to various visual expressions and movement-based interactions, contributing to future HCI applications promoting artistic legitimacy for disability art.

Our evaluation relies on a mixed approach. The preliminary study collected data during an interactive exhibition open to the general public. Secondly, an online survey was conducted with professional wheelchair dancers and choreographers. The results indicate that the visual solution effectively provided expressive information for movement exploration and quality assessment in wheelchair dancing.

2 BACKGROUND

2.1 Wheelchair Dance and Ableism

Disability art is still overshadowed by stigmatizing beliefs [Barbareschi et al. 2021], and disabled artists are often subject to incompetent discrimination [Morris 2015][Whitfield 2021]. Such limited representation is also common among wheelchair dancers [Whitfield 2021]. Notions around the aesthetics of proportioned bodies [Bresnahan and Deckard 2019], limit the artistic recognition of wheelchair dance and hinder its expression [Broyer 2017]. Moreover, Pavis et al 2017 [Pavis et al. 2017] reflects on how limited access to fixation tools, including LMA, can make it difficult for disabled artists to document choreographies they create, a necessary step to acquire and retain copyright, potentially affecting the artist's livelihood and legacy.

Disability studies challenge the idea of proportioned body aesthetics, building on the interpretations of Edmund Burke [Bresnahan and Deckard 2019]. Perception of beauty is a subjective experience that can be shaped by experience. Disabled artists' approaches to using their experiences to surpass traditional art practices demonstrate the necessity for a change in disability art. Wheeling dancers focus on movement dynamics beyond imitation of standing forms [Barbareschi and Inakage 2022]; disabled bodies express unique and disruptive movement paradigms [Barbareschi and Inakage 2022], and assistive technology blends into performance aesthetic [Whatley 2007]. Mainstream dance also expanded this artistic appreciation through inclusive experiences in embodied translation [Hammer 2021], or contact improvisations [Bresnahan and Deckard 2019]. These practices challenge and expand artistic expression, creating parallel approaches from established methods.

Despite the advances made by artists and activists, wheelchairs and other assistive technologies are still seen as a reminder of limitation that deviates dancers from artistic expression [Dancer 2007] [Whitfield 2021]. Researchers and wheeling dancers advocate re-characterizing wheelchairs as the extension of the body to redefine artistic expressions [Morris 2015], [Dancer 2007].

No study has explored artistic institutional movement analysis integrating wheelchair dance while considering the re-storying of wheeling artists' identities for aesthetic activism.[Müller 2020].

2.2 Effort Description

The movement carries emotional content like music, while dancers perform movements like storytellers to evoke feelings. Movement analysis systems, such as LMA, examine and convey dance messages [Guest 2005].

LMA, developed by Rudolph Laban in the 1920s, evaluates expressive quality as a reflection of the dancer's state of mind through the Effort description [Guest 2005]. LMA's Effort interpretations have been adopted in a wide range of HCI applications, including as affective input for interactive applications [Fagerberg et al. 2003].

The Basic Effort's primary motion factors Time, Weight, and Space are essential to capture movement qualities [Alaoui et al. 2017]. Time embodies the pace of movement; Weight is the amount of force exerted; and Space is the direction of attention (full definitions are shown in Figure

2) [Subyen et al. 2011]. These motion factors range between two opposite extremes. In human movements, Effort parameters not only coexist [Alaoui et al. 2017] but can emphasize or downplay each other [Subyen et al. 2011].

Visual art incorporates dance as a form of expression, allowing for cross-pollination of artistic languages and identities [Koss 2003]. Visualization allows for poetic [Subyen et al. 2011] and functional analysis [Preston 2014] of communication in dance. Laban Movement Analysis (LMA) visualizes movement and emotion through choreutics, integrating mental and physical aspects using the kinesphere[Sutil 2012; von Laban 1966]. Hence, its visualization unifies movement and mind in universal expression.

Motion Factor	Description	Continuum	Example
Time	Embodies the pace of movement	Sustained: Leisurely, slow	Taichi
		Sudden: Fast, haste	Quick Punch
Weight	Embodies the amount of fource excerted	Light: buoyant, force is decreased	Balloon flying
		Strong: powerful, force is increased	Weight Lifting
Space	Embodies the direction of attention	Direct: straight, single attention matching movement intent	Point out direction
		Indirect: deviating, multiple attentions with sinuous movement	Meandering

Fig. 2. Basic Effort Descriptions and Examples

2.3 Recognizing Body and Movement Quality

Traditionally, movement quality was captured through observation by professional notators, limiting access to a select few practitioners [Alaoui et al. 2017].

Technological advancements in motion capture, including optical-active, optical-passive, marker-based, markerless, and IMU-based technologies, enhance accessibility by automating the capture of movement quality. Data captured from mocap-suit can recognize style quality in folk dancing [Aristidou et al. 2015]. Kinect-facilitated motion capture has also been used for processing movement qualities [Anjos et al. 2018], whereas hybrid implementation combining IMU and vision-based sensors supported flexible movement tracking [Olugbade et al. 2023]. However, accessibility of these systems can be hindered by the requirements of knowledge, financial ability, and physical space for set-up. Therefore, a simpler video-based approach using smartphones or webcams can provide user-friendly motion capture for wheelchair dancers.

Moreover, current datasets in motion capture lack the embodiment of diverse body forms. No datasets were found for people with disabilities in sports, artistic expressions, or everyday tasks,

beyond medical questions like diagnosis or rehabilitation [Olugbade et al. 2023]. Research identifying movement quality is also limited to conventional bodies for data classification. Movement classification using Hidden Markov Models [Alaoui et al. 2017], and Isomap classification [Aristidou et al. 2015] on skeletal tracking, and rendering effects on body shapes[Anjos et al. 2018] focuses on the entire *abled* bodies or relies on segmented body motion with sufficient motion data.

Researchers have investigated capturing wheelchair movement in Human-Computer Interaction (HCI), such as using wheel rotation speed as input for dance games [Takeda et al. 2017] and sensing wheelchair users' propulsion gestures [Luna et al. 2022]. However, sensor attachments to the wheelchair or the person may impede dancers' movement and create a separation between the user and the wheelchair. Previous studies have shown that wheelchair dancers view their wheelchairs as an extension of their bodies [Barbareschi and Inakage 2022]. Therefore, we argue that when applying motion tracking for wheelchair dancers, such perspectives should be considered.

3 DESIGN SOLUTION

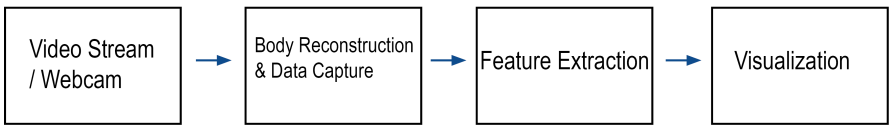

Fig. 3. Design Solution Flow Chart.

Our movement quality visualization tool focuses on wheeling dancers. The acquisition of spatial information is encrypted into memory through a process of cognitive mapping in dance [Longstaff 2000]. In Laban's Choreutics, a wheelchair dancer's mental imagery would encompass the wheelchair used in performance. Each body part can have its own kinesphere within the central kinesphere of the body [von Laban 1966]. Therefore, the dancer's body and wheelchair can be treated as a shared whole body with two kinespheres [Hammer 2021].

The design is articulated around three modules presented in the following sections: body reconstruction for data capture, movement feature extraction, and Effort visualization (Figure 3).

3.1 Body Reconstruction for Data Capture

We used Laban's theory of kinesphere to integrate the wheelchair as a body extension. This involved reconstructing the body's perception using grids (Figure 4). This method enables the selection and calculation of body landmarks acquired from the MediaPipe pose library[1], a machine-learning solution for live streaming media.

The three key elements of body reconstruction are:

- *Frontal Plane*: The Frontal Plane is an abstract coordination plane estimated by wrist, nose, ankles, and calculated midpoint of ankles as the body's periphery.
- *Main Kinesphere*: The main kinesphere is the center of the body, calculated between the hips for wheelchair dance considering the sitting position. The wheelchair shares the same kinesphere as other body parts.
- *Wheelchair Kinesphere*: The wheelchair's kinesphere is estimated from the midpoint on the diagonal line from the right hip to the left ankle.

The reconstruction of the body and wheelchair as a unified organism introduces a new perspective before applying motion data capture. As a result, we are able to extract 10 principal body landmarks

[1]Available at: https://google.github.io/mediapipe/solutions/pose.html

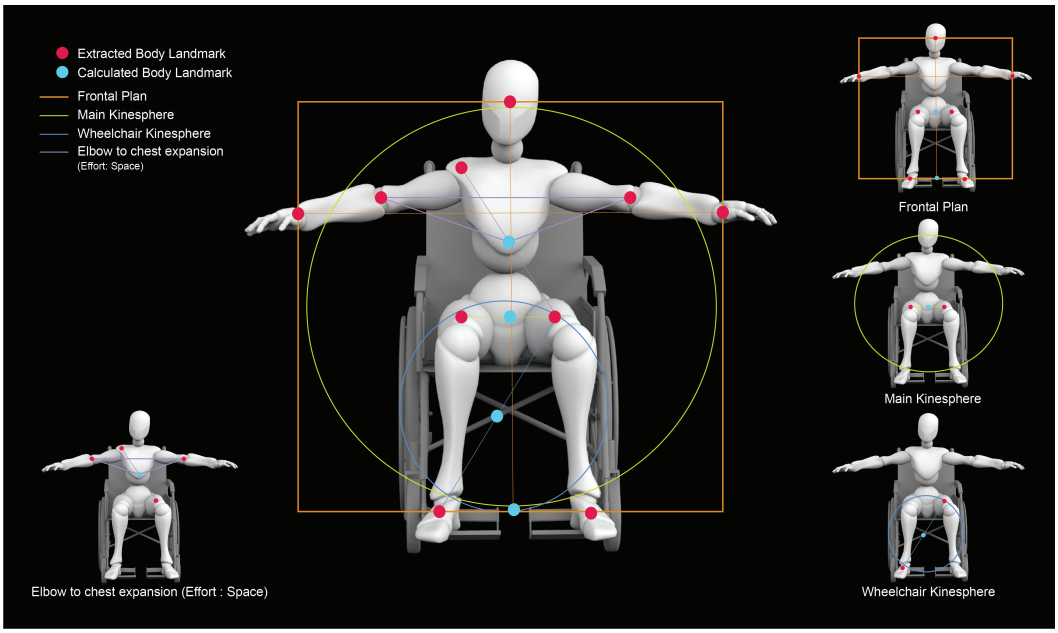

Fig. 4. Grid System for Body Reconstruction

from the 33 landmarks generated by MediaPipe. Additionally, three body landmarks were calculated: the center of the main kinesphere, the wheelchair kinesphere, and the chest center to help identify body formation in feature extraction.

3.2 Feature Extraction

The feature extraction relies on the Basic Effort description (Figure 5).

- *Time*: Wheelchair dancers use their upper limbs for expressive movements, with wrist speed conveying significant information. Time is determined using the rate of change of each wrist's position, calculated by the first derivative.
- *Weight*: Weight categorizes extension as Light and contraction as Strong. Wheelchair dance uses the wheelchair-center to identify extension, and upper body movements are categorized as Light or Strong based on their distance from the center, given limited lower body motion.
- *Space*: Focus-movement alignment determines Space, which is demonstrated using a grid compass that incorporates head direction and elbow-chest extension. Nose bearing from chest center reveals a dancer's focus direction, indicating Space quality. Experts also use elbow-chest distance to determine *Indirect* or *Direct* [Alaoui et al. 2017].

3.3 Effort Visualization

Our design uses blue and red to represent each side of the body. The extracted features are visualized utilizing affordance properties of line, color, and shape to convey perceptual information of movement quality (Figure 6).

- *Time*: Line length represents the perceptual sense of Time [Subyen et al. 2011]: a shorter line indicates *Sudden*, while a longer one indicates *Sustain* (Figure 6). To highlight Time, white

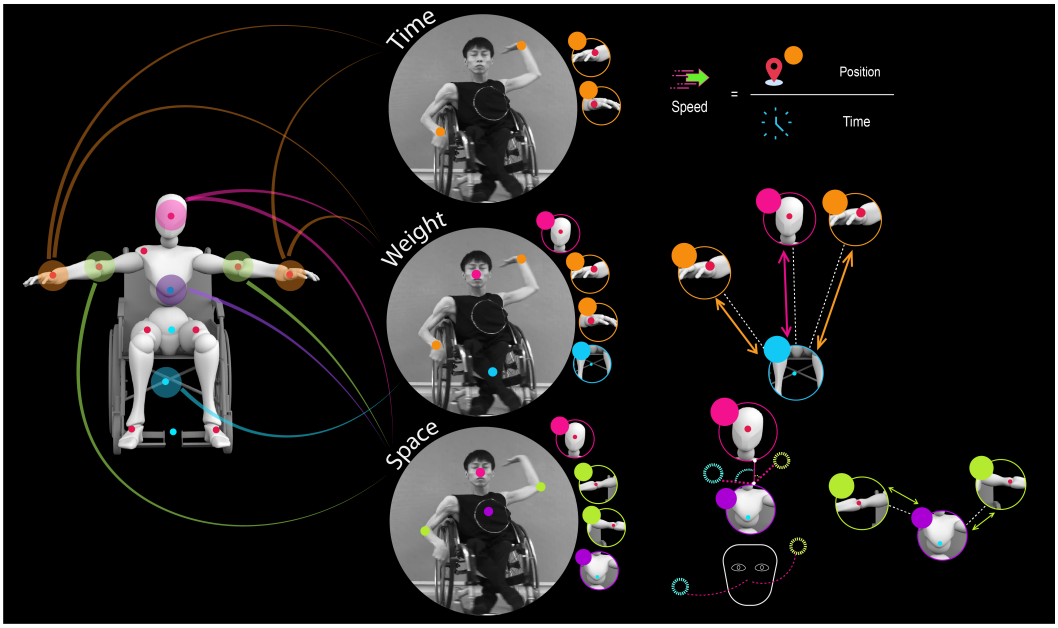

Fig. 5. Feature Extraction Referenced on Sun Dance Choreography © Kenta Kambara

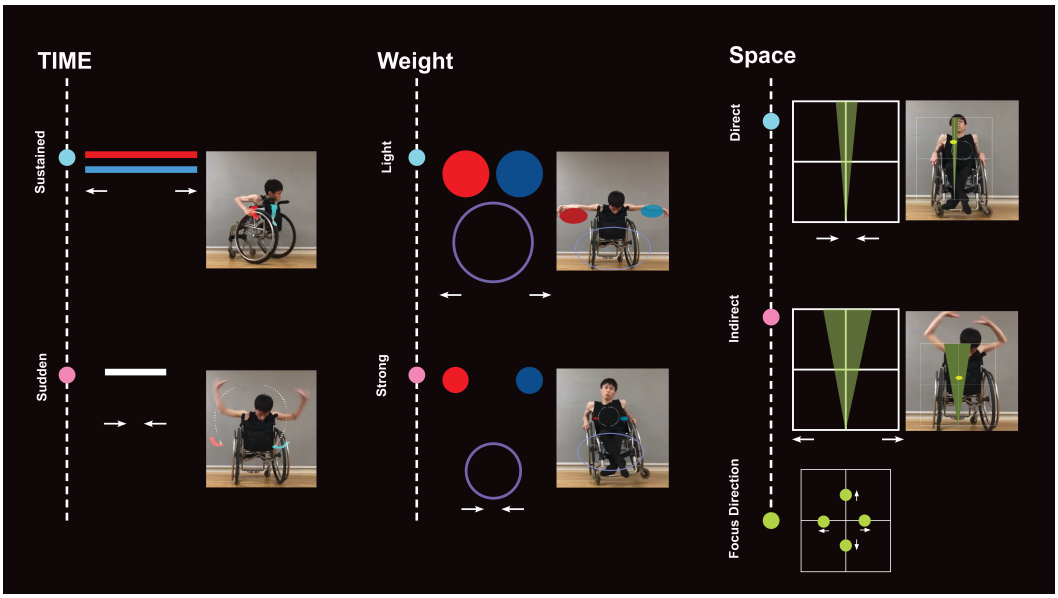

Fig. 6. Visualization of *Basic Effort* Referenced on Sun Dance Choreography © Kenta Kambara

is added to lines for Sudden quality. Wrist movement is continuously displayed over two seconds, emphasizing movement rather than pose.

- *Weight*: To visualize weight, we use three circles corresponding to the dancer's nose, left wrist, and right wrist. Scale increase indicates *Light* due to body extension, while decrease mimics contraction and represents *Strong*.
- *Space*: Space direction is shown using a compass centered at the main kinesphere, with a dot on the Frontal Plane (Figure 6), compared to wrist trajectory. The triangle grid (Figure 4) displays Space quality via elbow-to-chest distance.

The visualization conveys LMA effort quality, allowing readers to evaluate dance and inspire movement exploration. Different visual quality is assigned to each effort for separate evaluation and unified analysis. The abstract visual transcends wheelchair as body extension and artistic persona while omitting stigmas by shifting focus from normalized forms to the quality and intention within dance. Crucially, this approach adapts established LMA to align with conventional dance, liberating the distinctiveness of wheelchair dance.

4 EVALUATION

The design of our movement quality visualization was evaluated through a pilot study as part of a public exhibition followed by a targeted online questionnaire. We showcased the interactive visualization at a public exhibition, KMD Forum, recruiting 25 participants from the general public in November 2022. Participants sat on a wheelchair and performed guided movements associated with *Time*, such as reaching upward at different speeds, while facing a webcam as an input device and the visualization's real-time display. Participants were also shown generated *Time* visualization of professional wheelchair dancer Kenta Kambara's Sun Dance (Figure 7) and asked to identify Effort quality in multiple-choice questions (Figure 8).

Based on feedback from the study, our visualization was refined as shown in Figure 9. Excessive visual elements were reduced, shorter lines now indicate Sudden in *Time*, and overlapped effort-visuals were used for a holistic representation of movement.

Fig. 7. Interactive Exhibition (2022): a. and b. interaction with the visualization, c. visualization in real-time, d. survey example.

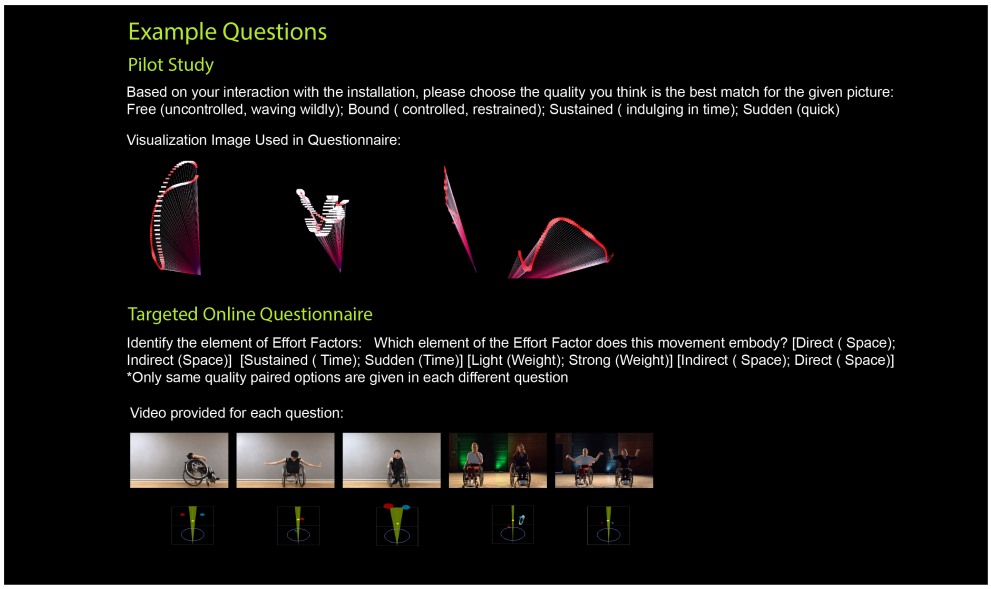

Fig. 8. Questionnaire(2022). Reference Images from Sun Dance © Kenta Kambara

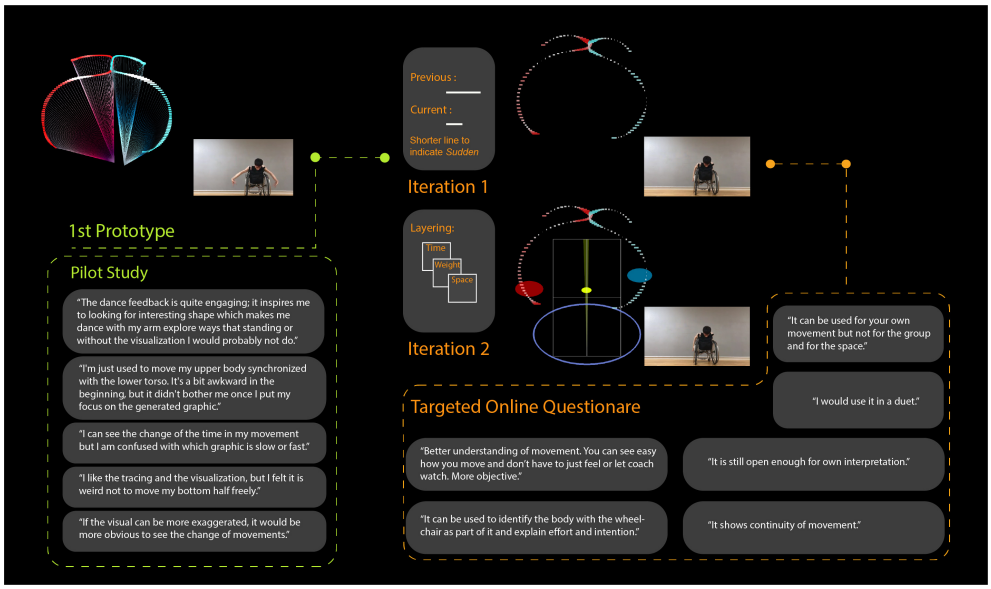

Fig. 9. Iteration and feedback(2022-2023). Reference Images from Sun Dance © Kenta Kambara

We gave questionnaires to two experienced wheelchair dancers and a choreographer to assess the ease of understanding and artistic meaningfulness of our visualization (Figure 10). The questionnaire asked about the dancers' background, identification of Effort on the provided visualization, and feedback (the full copies of the questionnaires are included in the supplementary material).

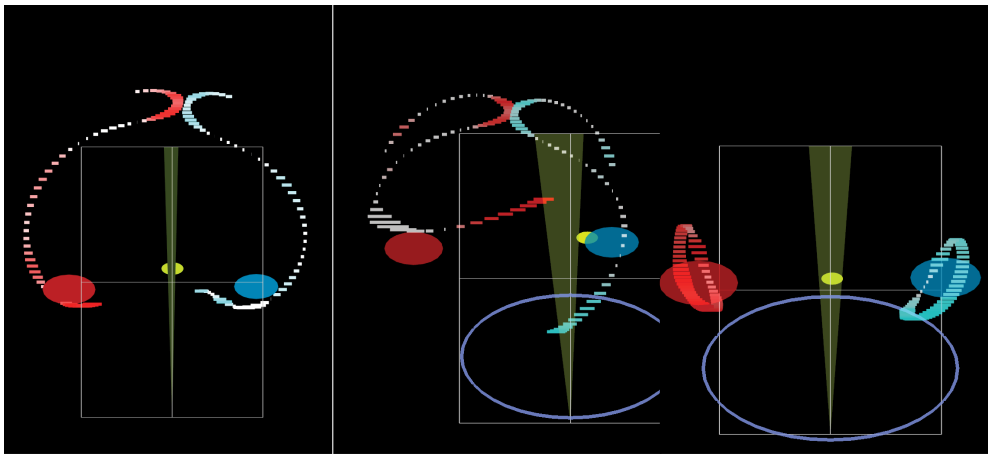

Fig. 10. Visualization generated from Sun Dance © Kenta Kambara

Effort visualization helped first-time wheelchair dancers explore movement possibilities and recognize Time (Figure 9). Professional dancers reported that the visualization provided objective feedback and conveyed the intention of movement during dance (Figure 9).

Professionals stated they would like to use these visualizations for real-time performance, representation of intention, and objective evaluation (Figure 9). Two participants suggested using a more objective visual representation of the dancer's body, such as partially preserving the original body form, and additional visualization of rhythm to identify movement quality. One participant also suggested expanding the visualization solution towards multiple or grouped dancers.

5 CONCLUSION AND FUTURE WORK

Our visualization solution creates visual notation of LMA Basic Effort, expressing the artistic value of wheelchair dancing by combining the idea of the wheelchair as an extension of the body with body reconstruction and experiential concepts of beauty in dance. Our visual notation of LMA Basic Effort provides an objective interpretation of movement quality and enhances wheelchair dance exploration and evaluation. This approach expands the artistic capacity of wheelchair dance among professionals and general audiences.

The research aimed to integrate disability art into the mainstream art world by applying artistic measures in wheelchair dance. Initial testing results demonstrate that the system can benefit wheeling artists in movement exploration, education, performance, and communication with the established dance community. Further implementations will investigate how theoretical measures in disability art contribute to its artistic legitimacy. The visualization of LMA movement quality facilitates a parallel practice from LMA methodology and expresses artistic value beyond physical disability.

The design fosters inclusive movement analysis in HCI and challenges stigmatized ableism through assistive tools as artistic resources, opening an artistic perspective on engaging non-normative bodies. We argue that the proposed solution extends motion tracking and movement data processing to diverse body-forms, where emerging technology, such as mobile motion capture devices can foster holistic LMA in wheelchair dance. This design has potential applications in HCI for performance, digital education, and other contexts. Future development could explore incorporating multiple dancers and groups with diverse body forms.

We plan to conduct studies with wheelchair dancers using our design for movement mirroring and choreography. The expertise of wheelchair dancers can re-contextualize LMA and foster inclusiveness towards diverse bodies. We are refining our visualization of Basic Effort for a better embodiment of movement quality, as well as working to include scenarios where the dancer gets off the wheelchair during the performance, separating the two existing kinespheres.

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